Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 146 (2016) 350 – 358

Procedia Engineering

www.elsevier.com/locate/procedia

8th International Cold Climate HVAC 2015 Conference, CCHVAC 2015

Influence of air-conditioning outdoor unit arrangement strategy on energy consumption

Ran Duan[a,] *, Xin Wang[b], Yue Song[b], and Jiagen Liu[a]

[a]Beijing Tsinghua Tongheng Urban Planning & Design Institute, Room 1222, Building Jia 1, East Qinghe Jiayuan, Middle Qinghe Street, Haidian District, Beijing and 100085, China.
[b] Beijing Persagy Energy Efficiency Technology Ltd, Beijing and 100084, China.

Abstract

How to prevent the hot air entering the outdoor unit is thus critical for Split-type air conditioner (AC) operation temperature control. This investigation studied the influence of louver installation (angle and spacing) and outdoor AC unit arrangement (style and location) on the system ventilation using computational fluid dynamics (CFD) technique. With the louver spacing increasing and the distance between neighbouring outdoor AC units decreasing, the working temperature increases. Considering heat dissipation and protecting machines from rainwater, the optimum louver angle is 100 degrees. The vertical arrangement for outdoor units is more beneficial to exhaust hot air than the horizontal arrangement. In conclusion, in order to reduce operation temperature while saving energy, the following design points are recommended:
a. Vertical arrangement for outdoor units;
b. Larger distance between neighbouring outdoor units;
c. Smaller louver spacing;
d. 100 degrees for the louver angle.

Peer-review under responsibility of the organizing committee of CCHVAC 2015

Keywords: Angle and spacing of louver, Arrangement and location of air-conditioning outside unit, High-rise building;

* Corresponding author. Tel.: +86-10-82819000; fax: +86-10-62771154.
E-mail address: duanran@thupdi.com

Peer-review under responsibility of the organizing committee of CCHVAC 2015
doi:10.1016/j.proeng.2016.06.409

1. Introduction

Nowadays, split-type air conditioners are widely used. The operation temperature of air-conditioning outdoor units has a significant effect on the coefficient of performance (COP) of air conditioners (Chow et al 2002 and Barreira et al 2013). High working temperature could decrease the efficiency of split-type air conditioners and increase the energy consumption. Sometimes it results in that outdoor units stop working. However, large demand and limited installation space for split-type air condition outdoor units in high-rise residential buildings would enhance the thermal buoyancy and raise the working temperature of air-conditioner outdoor units. Therefore, how to prevent the hot air entering the outdoor unit is critical for ACs operation.

Nomenclature

b	the source term or boundary conditions
ϕ	the flow variables (velocity, enthalpy, and turbulence parameters)
ϕ_p	the variable of the present cell
ϕ_{nb}	the variable of the neighbouring cell
α_p	the coefficient of the variable at the present cell
α_{nb}	the correlation coefficients of the variable of the neighbouring cells
$\Gamma\phi,eff$	the effective diffusion coefficient
$S\phi$	the source term

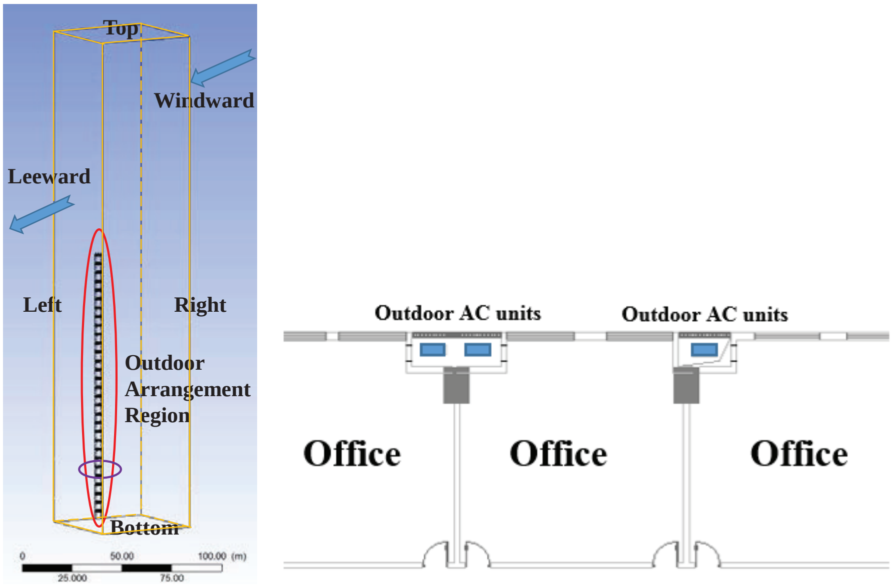
Significant effort has been made in recent years to optimize the operation temperature of outdoor AC units by CFD. For example, Xue et al (2007) found that it could attenuate the temperature rise if the blowing angle of condenser fans titled upward. Avara and Daneshgar (2008) recommended various optimum distances between outdoor AC unit and supporting wall in different conditions. Bojic et al (2002) showed that deeper recessed space placing condensing units was good for inner condenser units but do harm to some outer condenser units. Chow et al (2001) investigated that using a light well for the discharge of cooling air from the condensing units of the split-type air conditioners had better energy performance than the case when condensing units are being placed inside a building re-entrant. Chow et al (2000) found that T-shaped re-entrant had best energy performance compared with I-shaped and L-shaped re-entrant which outdoor condenser placed on. Choi et al (2004) investigated that operation temperature rose with outdoor wind speed increasing. However, few research were focused on the influence of louver parameters and outdoor AC unit arrangements on the heat dissipation of outdoor AC units. Due to the research gap, this study used CFD to investigate the effect of louver setting and outdoor AC unit arrangement on the working temperature of outdoor AC units, and proposed some design recommendations. It can be further developed as a strategy for building energy saving.

2. Methods

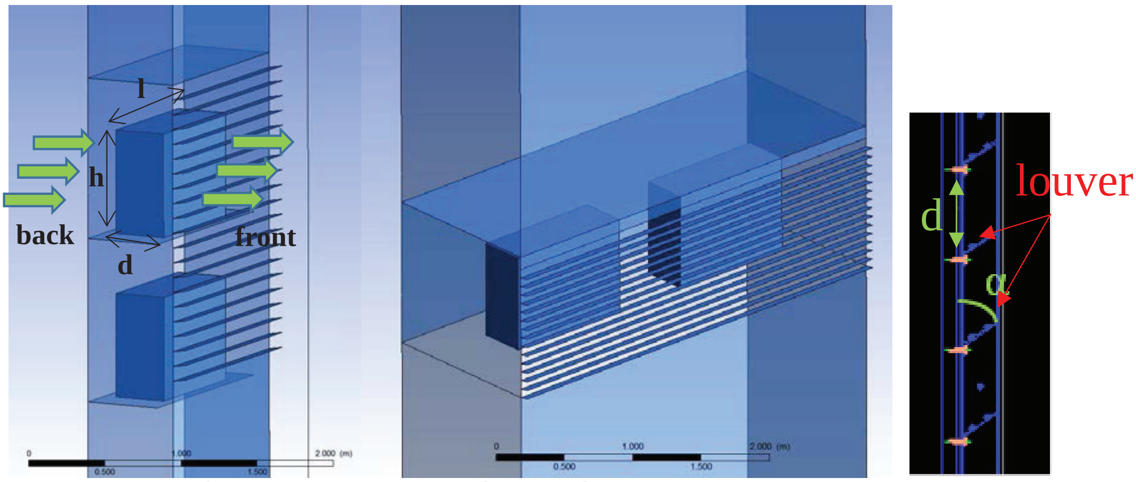
2.1. The test cases

Fig. 1 showed air-conditionings installed on the outdoor wall of a 30-storey high-rise apartment building in Chongqing, China. Considering the effect of outside wind, the computational domain is extended 50 m from the building front wall and 24 m from the left and right walls of building. To analyse the rising flow, the computational domain is extended 115 m above the top of the building, as shown in Fig. 1(a). The outside temperature of the summer design specification was assumed to be 36.3℃ in Chongqing. Considering that outdoor wind could influence outdoor AC units arrangement style, this research assumed breeze from right with 0.2m/s instead of no wind.

The ACs installation locations were showed in Fig. 1(b). All ACs operated simultaneously at full loads, which was the worst operating condition. The outdoor AC unit exhausted hot air from its front with a heat dissipation rate of 3.5 kW. There are two arrangement styles, as shown in Fig. 1(c) and (d). Louvers are used to enhance the building appearance, and its spacing d and angle α is showed in Fig. 1 (e). This investigation studied the influence of louver installation (angle and spacing) and outdoor AC unit arrangement (style and location) on the system ventilation. Table 1 showed all test cases in this study. There are two ACs placing in each storey. The louver width is 50 mm.



(a) Computation domain (b) Installation location of outdoor AC units



(c) Vertical arrangement (d) Horizontal arrangement (e) Louver arrangement

Fig.1. Schematic of computational domain; installation location and arrangement mode of outdoor AC units; and louver arrangement

Table 1. Compared various working conditions of outdoor AC units

	Distance between Neighbouring Outdoor AC Units	Louver Spacing	Louver Angle α	Arrangement Style
Research A	0.3m	50mm	80°	Vertical Arrangement Horizontal Arrangement
Research B	0.3m 0.5m 0.7m	50mm	80°	Vertical Arrangement
Research C	0.7m	40mm 50mm 100mm 150mm 200mm	80°	Vertical Arrangement
Research D	0.7m	50mm	60° 70° 80° 90° 100° 110° 120°	Vertical Arrangement

3. Numerical method

CFD technique was widely used to analyse air-conditions heat dissipation (Xue et al 2007 and Chow et al 2001). The Standard k-ε model was commonly adopted by other researches (Choi et al 2004, Avara and Daneshgar 2008). The governing equations for the Standard k-ε model can be written in a general form:

$$\rho \frac{\partial \overline{\phi}}{\partial t} + \rho \overline{u_i} \frac{\partial \overline{\phi}}{\partial x_i} - \frac{\partial}{\partial x_i}[\Gamma_{\phi,eff} \frac{\partial \overline{\phi}}{\partial x_i}] = S_\phi \tag{1}$$

where ϕ represents the flow variables (velocity, enthalpy, and turbulence parameters), $\Gamma\phi,eff$ is the effective diffusion coefficient, and $S\phi$ is the source term. When ϕ=1, $\Gamma\phi,eff$ and $S\phi$ equal zero, equation (1) then turn into the continuity equation.

This research used commercial CFD software, FLUENT (ANSYS 2010) for all the numerical simulations. The software adopted the SIMPLE (Patankar 1980) algorithm to couple the pressure and velocity calculation. The Boussinesq approximation was used to consider the air density changes resulting from the heat dissipation of outdoor AC units. The Standard scheme was adopted for pressure discretization and the first-order upwind scheme was for all the other variables. The study considered the solutions to be converged when the sum of the normalized residuals for all the cells satisfied the conditions (less than10-6 for energy and 10-3 for all other variables). The normalized residuals were defined as:

$$R_\phi = \frac{\sum_{cellsP} \left| \sum_{nb} a_{nb}\phi_{nb} + b - a_P\phi_P \right|}{\sum_{cellsP} \left| a_P\phi_P \right|} \tag{2}$$

where ϕ_P and ϕ_{nb} are the variable of the present and neighbouring cells, respectively; a_P is the coefficient of the variable at the present cell; a_{nb} are the correlation coefficients of the variable of the neighbouring cells; and b is the source term or boundary conditions.

4. Results

4.1. Effect of the outdoor AC unit arrangement

Fig. 2 showed that the suction temperature of outdoor AC units in horizontal arrangement was higher than that in vertical arrangement. Due to the influence of outdoor wind direction, the downstream outdoor units inhaled the hot air that was exhausted from upstream outdoor units. The suction temperature of the downstream outdoor units was obviously higher than that of upstream outdoor units. Therefore, the outdoor AC units in vertical arrangement were better for heat dissipation of the system.

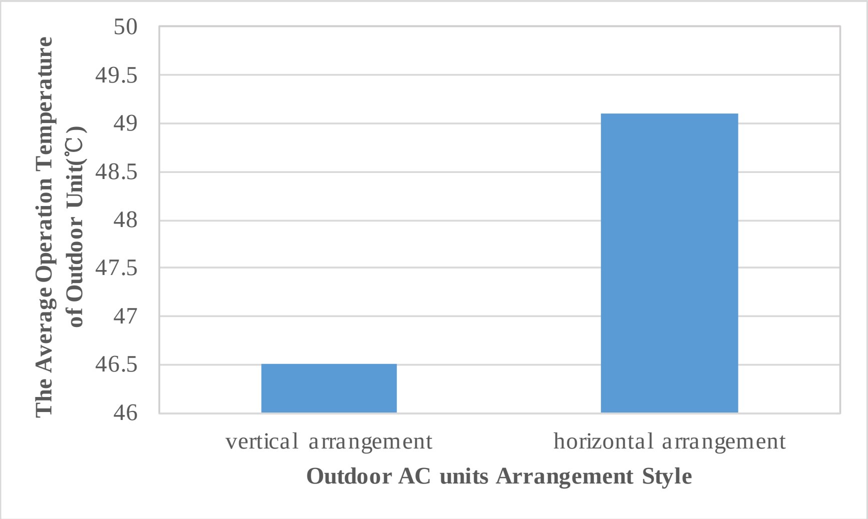


Fig. 2. Relationship between the average operation temperature and the outdoor AC unit arrangement mode

4.2. Effect of the distance between neighbouring outdoor AC units

As shown in Fig. 3, increasing the distance between neighbouring outdoor AC units resulted in lower operation temperature, indicating that a larger distance was more beneficial for the dissipation of exhausted hot air. The suction temperature with the distance of 0.3 m was 4.5℃ higher than that with the distance of 0.7 m.

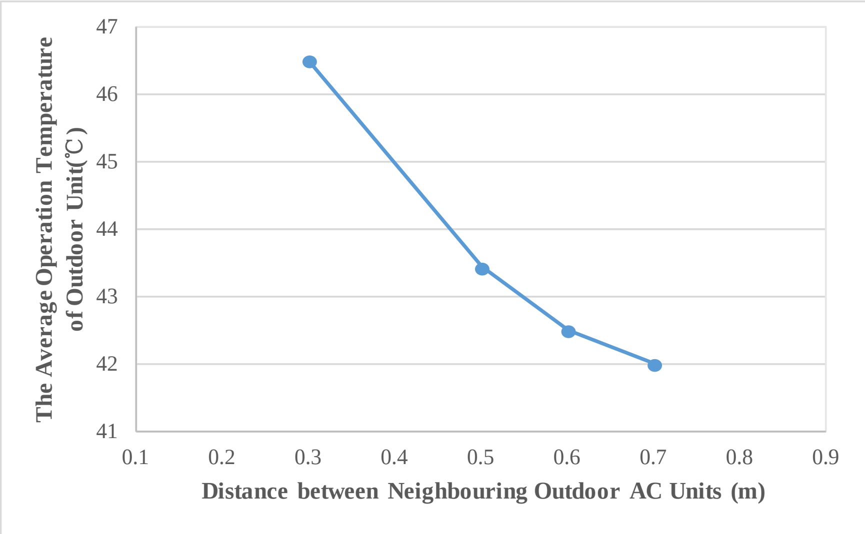


Fig. 3. Relationship between the average operation temperature and the distance between neighboring outdoor AC units

4.3. Effect of the louver spacing

As shown in Fig. 4, with increasing of the louver spacing, the working temperature increased. However, there was no significant influence on the results whether the louvers spacing was too small (＜0.05m) or over large (＞0.15m). Louvers could be used to effectively dissipate heat because they could lead their surrounding airflow. When louver spacing increased, louver couldn't induce airflow far away from it. Therefore, smaller louver spacing was better for heat dissipate. However, the temperature difference was less than 1℃ with varying louvers spacing. Therefore, considering that smaller louver spacing had smaller effectively ventilation area and high costs, this research recommended that louver spacing was larger than 0.05 m.

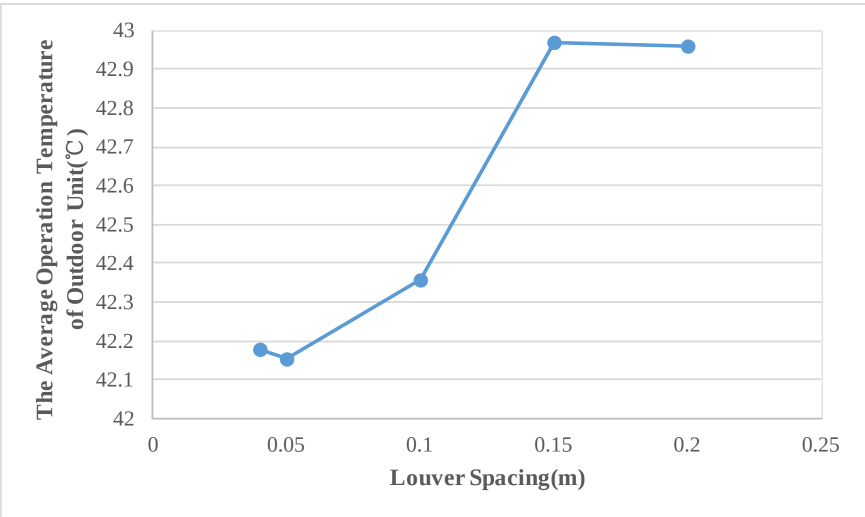


Fig. 4. Relationship between the average operation temperature and louver spacing

4.4. Effect of the louver angle

Fig. 5 showed that the optimum louver angle to exhaust hot air was 80 degrees. Whether the louver angle increased or decreased, the working temperature of outdoor AC units would increase. When louver angle was less than 80 degrees, smaller louver angle enhanced thermal buoyance, which drives hot air upward as shown in Fig. 6 and led to resulted that exhausting air of outdoor AC units was inhaled by outdoor AC units installed at the upper floors. Therefore, the suction temperature of outdoor AC units installed at the upper floors would increase. When louver angle was larger than 80 degrees, larger louver angle was also worse to heat dissipate. It increased the suction temperature of outdoor AC units installed at the lower floors that the louver drove hot air to lower floors as shown in Fig. 6. However, in order to protect machines from rainwater, this research recommended 100 degrees.

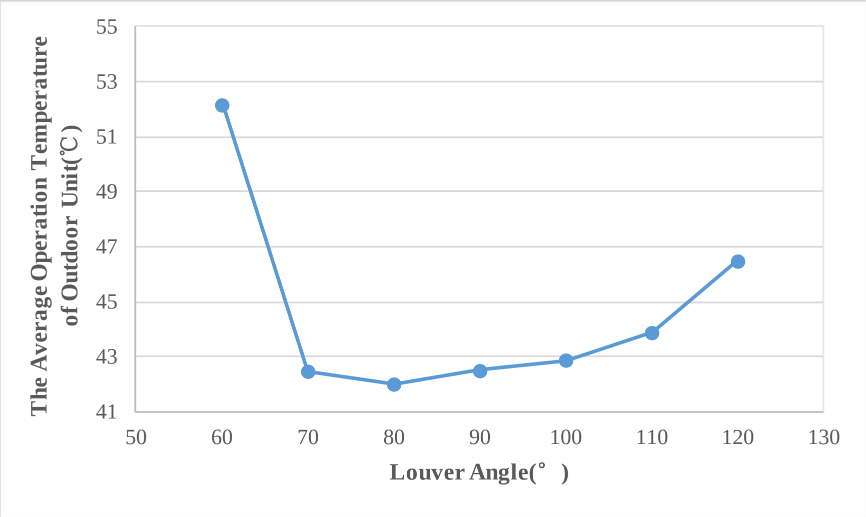


Fig. 5. Relationship between average operation temperature and louver angle

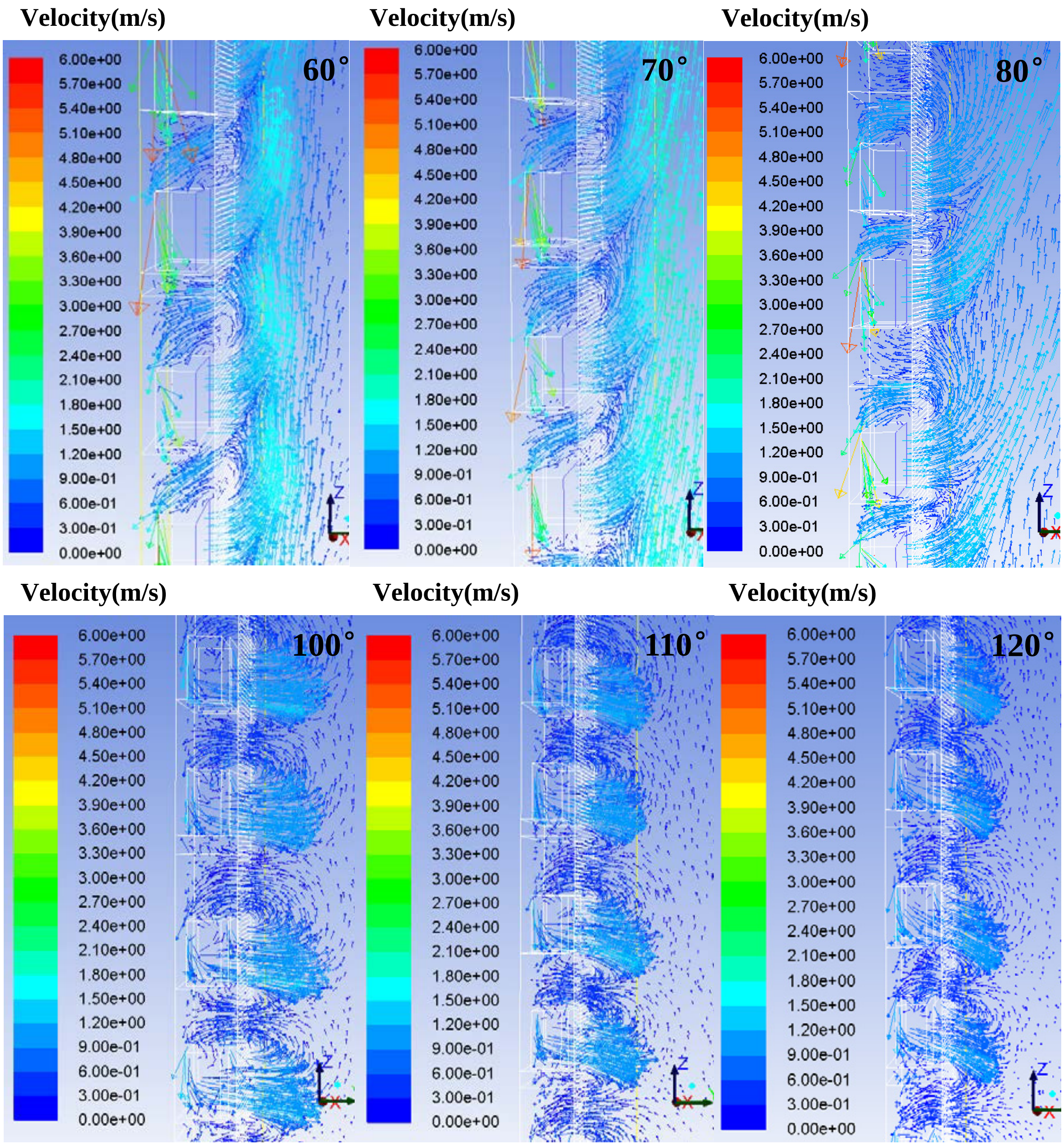


Fig. 6. Comparison of the airflow patterns simulated with different louver angles

5. Conclusions

In conclusion, various factors have combined effects on the suction air temperature of outdoor AC units. The heat dissipation of outdoor AC units was primarily affected by outdoor unit arrangement style and distance, as well as the louver angel. In order to reduce the operation temperature and save energy, the following recommendations are suggested according to this study：

a. Vertical arrangement for outdoor units;

b. Larger distance between neighbouring outdoor units;
c. Smaller louver spacing;
d. 100 degrees for the louver angle.

REFERENCES

[1] ANSYS Fluent 13.0 Documentation. Fluent Inc., Lebanon, NH, 2010

[2] A. Avara, and E. Daneshgar, Optimum placement of condensing units of split-type air-conditioners by numerical simulation. Energy & Buildings, 2008, 40(7), 1268–1272.

[3] E.M. Arreira, C.O.R. Negrão and C.J.L. Hermes, Thermoeconomic analysis and optimization of residential split-type air conditioners. Applied Thermal Engineering, 2013, 50(1), 629–636.

[4] M. Bojic, M. Lee, and F. Yik, Influence of a depth of a recessed space to flow due to air-conditioner heat rejection. Energy & Buildings, 2002, 34(1), 33-43.

[5] S.H. Choi, K.S. Lee and B. S. Kim, Effects of stacked condensers in a high-rise apartment building. Energy, 2005, 30(7), 968-981.

[6] T.T. Chow, Z. Lin, and Q. W. Wang, Flow analysis of condenser cooling air delivery via building light well. Applied Thermal Engineering, 2001, 21(8), 831-843.

[7] T.T. Chow, Z. Lin, and Q. W. Wang, Effect of building re-entrant shape on performance of air-cooled condensing units. Energy & Buildings, 2000, 32(2), 143-152.

[8] T.T.Chow, Z. Lin, and X.Y.Yang, Placement of condensing units of split-type air-conditioners at low-rise residences, Applied Thermal Engineering, 2002, 22(13), 1431–1444.

[9] S. Patankar, Numerical heat transfer and fluid flow. Washington Dc Hemisphere Publishing Corp.p, 1980, 27(1), 125–126

[10] H. Xue, B. Xu, J. Wu, and Y. Wei, Prediction of temperature rise near condensing units in the confined space of a high-rise building. Building & Environment, 2007, 42(7), 2480–2487.